C.2 ANGLE MEASUREMENT SYSTEMS

There are three different methods of measuring the azimuth and elevation angle of a free flying balloon with respect to the ground station: optical observation (optical theodolite), radio direction finding (RDF or radiotheodolite), and active tracking by radar.

Both types of theodolite need the hydrostatic height measured by the radiosonde whereas the radar requires only a reflector.

C.2.1 OPTICAL THEODOLITE

The optical theodolite is a simple and inexpensive means to measure the winds. An operator manually tracks the motion of a balloon with the theodolite. Weather is its most severe limiting factor. The modern optical theodolites (Automatic Optical Theodolite, AOT) have a computer interface in order to read the angles automatically, allowing the system to be operable by one person. The height can be approximated assuming a constant rate ascent for the radiosonde, which incorporates unnecessary inaccuracy into the measurement, or use the hydrostatic height computed from the radiosonde data. The advantages of an automatic optical theodolites are:

+ simplicity
+ accuracy at low level
+ reliability of equipment
+ lowest level less than 100 m
+ good mobility
+ good maintainability
+ passiveness
+ independent of remote transmitters
+ good electromagnetic compatibility

The optical tracking is very dependent on the weather conditions, which is its principle disadvantage:

- useless in severe weather

- maximum height limited by cloud base
- accuracy depends on the distance
- accuracy depends on the operator's skill
- the operator needs to track the balloon continuously
- two operators needed in release
- radiosonde is needed for accurate height and wind determination
- improper position fix
- not usable aboard ships or mobile platforms

C.2.2 RADIO DIRECTION FINDER (RDF)

The radiotheodolite, or RDF, operates by tracking the position of a radio frequency emitter (radiosonde). There have been several attempts to allocate the frequency of radiotheodolites in an optimal way. Systems using 25 MHz and 400 MHz have been realized but the 1680 MHz system is superior to the others. Some RDFs are also functioning as second survey radars sending a radio pulse, which is received by the radiosonde, amplified, and retransmitted to the ground station. These are called transponder systems. They determine the range fairly accurately, like radars, but lack the major advantages of an RDF, compared to radars, namely simplicity and passiveness. They also require a complex radiosonde with receiver and retransmitter.

The popularity of the RDF among certain user groups is due to three major factors. First, the system is passive, surviving radiation seeking missiles (unlike radars). Second, the system is independent of remote transmitters (unlike navaid-based systems). Finally, modern computer technology makes extensive data quality control possible, which improves data reliability. The advantages are:

+ simple construction (compared to radar)
+ independence
+ passiveness
+ adequate accuracy (for ballistic corrections)
+ good mobility

+ all-weather system

There are also many disadvantages:

- electromechanical system
- after processing, winds are too smooth
- without processing, winds are unreliable
- accuracy depends on range (100 km max.)
- requires two operators
- always requires a radiosonde
- improper position fix
- expensive for shipboard use

C.2.3 RADAR (RADIO DIRECTION AND RANGE FINDER)

The windfinder radars have been a very common means for wind observations but their use is declining due to the fast development of small and inexpensive navaid-based systems and new generation RDFs with ample processor capacity. The radars are still justified for windfinding in special cases, where the main purpose is in another domain of interest. Special radar installations are expensive and they are not purchased only for windfinding purposes. The best comparisons and reports concerning windfinding by radars refer to special radar installations. The basic windfinder radar has relatively few advantages:

+ radiosonde is not needed for wind observation
+ rather accurate at low levels
+ in good weather the first level is about 300 m
+ independence

The list of disadvantages is fairly long, which explains their declining use:

- complex electromechanical system
- loses the target easily
- requires two to three operators

- accuracy depends on range
- refraction and reflections cause uncorrectable errors
- automatic quality control is not normally included in the system
- without automatic quality control, manual work is required
- maintenance requires special expertise
- heavy reflector requires big balloon and much gas
- active radiating system
- improper position fix

C.3 REMOTE SENSING

Remote sensing for windfinding can use either acoustic or electromagnetic radiation. In order to measure horizontal and vertical wind components at least three beams are required, where one beam is pointed vertically and the two others are tilted off zenith and at right angles to each other. The antennas transmit pulses in sequence, which are backscattered from the atmosphere and received by the antennas, giving a three-dimensional picture of the movement of the scatterers. The scatterers are small scale temperature and humidity fluctuations in the atmosphere moving with the wind. The movement (wind) is computed from the Doppler shifts of received backscattered signals.

C.3.1 SODAR (ACOUSTIC RADAR)

The atmosphere scatters and absorbs sound waves much more strongly than it does electromagnetic waves. This limits the maximum altitude of sodars to 1.5 km or less. Because the sonic speed is very low compared to electromagnetic waves, the lowest altitude sampled is near the surface and the resolution is good. Sodar is justified in some applications by its simplicity and low cost, but its dependence on weather makes it less useful during severe conditions when the data are most important. Sodars also get reflections from temperature inversion layers, allowing such features to be monitored continuously during development. The advantages of sodars are:

+ continuous operation

+ good vertical resolution
+ first level about 50 m
+ unattended operation
+ inexpensive
+ the height of temperature inversion layer can be monitored
+ good electromagnetic compatibility
+ passiveness
+ independence
+ radiosonde is not needed
+ proper position fix

The disadvantages are few but severe:

- nearly useless in heavy wind
- useless in rain
- vertical range 50 m - 1500 m or less

C.3.2 CLEAR-AIR RADARS (WIND PROFILERS)

The wind profiler represents the newest technology making use of the recent developments of computers and radiotechnology. Its indisputable merits are the automatic, continuous, all-weather operation, and high accuracy; its main disadvantage is the relatively high investment cost of the larger systems. The wind profiler is the only means to provide wind observations from remote, unattended sites and continuous profiling with a proper position fix to high altitudes. These features make it suitable for both synoptic scale and mesoscale observations. The principal advantages are:

+ continuous profiling
+ low-operating costs and low life-cycle cost
+ vertical range 100 m - 18 km
+ fast profiling
+ three-dimensional profiles
+ fairly immune to weather conditions
+ remote, unattended operation
+ radiosonde is not used

+ independence
+ proper position fix

The disadvantages are:

- relatively high investm
tems)
- poor mobility, except f
ited performance)
- active electromagnetic

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WIND PROFILERS)

ι :st technology making use of nd radiotechnology. Its indis- ɔus, all-weather operation, and the relatively high investment filer is the only means to pro- attended sites and continuous igh altitudes. These features and mesoscale observations.

-cycle cost

ions

+ independence
+ proper position fix

The disadvantages are:

- relatively high investment costs (except for the smaller systems)
- poor mobility, except for the smaller systems (which have limited performance)
- active electromagnetic system

REFERENCES

Literature cited in this document is listed below.

Atlas, D., Srivastava, R.C., Carbone, R.E., and Sargeant, D.H., "Doppler cross-wind relations in radio troposcatter beam swinging for a thin scatter layer," *J. Atmos. Sci., 26*, 1104–1117, 1969.

Balsley, B.B. and Farley, D.T., "Auroral zone winds detected near the tropopause with the Chatanika UHF Doppler radar," *Geophys. Res. Lett., 3*, 525–528, 1976.

Balsley, B.B., Ecklund, W.L., Carter, D.A., and Johnston, P.E., "The Poker Flat MST radar: First results," *Geophys. Res. Letters, 6*, 921–924, 1979.

Battan, L.J., "Radar Observations of the Atmosphere," Univ. Chicago Press: Chicago, Illinois, 1973.

Bean, B.R. and Dutton, E.J., "Radio Meteorology," U.S. Government Printing Office, Washington, D.C., 1966.

Birkemeier, W.P., Fountaine, A.B., Gage, K.S., Gronemeyer, S.A., Jasperson, W.H., and Sechrist, F.S., "Wind measurements using forward-scatter CW radar," *J. Appl. Meteor., 12*, 1044–1053, 1973.

Browning, K.A., Starr, J.R., and Whyman, A.J., "Measurements of air motions in regions of clear air turbulence using high power Doppler radar," *Nature, 239*, 267–269, 1972.

Carlson, H.C., Jr. and Sundararaman, N., "Real-time jetstream tracking: National benefit from an ST radar network for measuring atmospheric motions," *Bull. Am. Meteor. Soc., 63*, 1019–1026, 1982.

Czechowsky, P., Klostermeyer, J., Rottger, J., Ruster, R., Schmidt, G., and Woodman, R.F., "The SOUSY VHF radar for tropospheric, stratospheric and mesospheric sounding," *Preprints, 17th Conference on Radar Meteorology (Seattle)*, AMS, Boston, 349–353, 1976.

Dobson, E.B., "Doppler radar measurements of mean wind variations in the clear atmosphere," *Preprints, 14th Conference on Radar Meteorology (Tucson)*, AMS, Boston, 69–78, 1970.

Doviak, R.J. and Zrnic, D.S., "Doppler Radar and Weather Observations," Academic Press, Inc.: Orlando, Florida, 1984.

Ecklund, W.L., Carter, D.A., and Balsley, B.B., "Continous measurement of upper atmospheric winds and turbulence using a VHF Doppler radar," *J. Atmos. Terr. Phys., 41*, 983–994, 1979.

Ecklund, W.L., Carter, D.A., and Gage, K.S., "Sounding of the lower atmosphere with a portable 50 MHz coherent radar," *J. Geophys. Res., 82*, 4969–4971, 1977.

Farley, D.T., Balsley, B.B., Swartz, W.E., and La Hoz, C., "Tropical winds measured by the Arecibo radar," *J. Appl. Meteor., 18*, 227–230, 1979.

Gossard, E.E. and Strauch, R.G., "Radar Observation of Clear Air and Clouds," Elsevier Science Publishing: New York, 1983.

Green, J.L., Warnock, J.M., Winkler, R.H., and VanZandt, T.E., "Studies of winds in the upper troposphere with a sensitive VHF radar," *Geophys. Res. Lett., 2*, 19–21, 1975.

Strauch, R.G., Merritt, D.A., Moran, K.P., Earnshaw, K.B., and Van de Kamp, D., "The Colorado wind-profiling network," *J. Atmos. and Oceanic Tech., 1*, 37–49, 1984.

Tatarskii, V.I., "The effects of the turbulent atmosphere on wave propagation," U.S. Dept. of Commerce National Technical Information Service TT-68-50464, 1971 (Translated from the Russian by Israel Program for Scientific Translations).

Woodman, R.F. and Guillen, A., "Radar observations of winds and turbulence in the stratosphere and mesosphere," *J. Atmos. Sci., 31*, 493–505, 1974.

APPENDIX B

Wind Profilers at 449 MHz

By:

Rick Palm, K1CE, Field Services Manager,

Wind Profilers at 449 MHz

The government plans to place new Doppler radar systems for better weather forecasting at a popular repeater frequency, but the news isn't all bad.

By Rick Palm, K1CE
Field Services Manager

It comes as a shock to some that we amateurs don't have exclusive use of all of "our" bands. More shocking sometimes is the fact that we don't even have priority use: In most of the UHF and higher bands, Amateur Radio is actually *secondary* to primary government radiolocation (military radar) and other services. If you don't believe it, look in the FCC's Table of Frequency Allocations in Part 2 of its Rules, or glance at your own copy of Part 97 where these arrangements are manifested. The US government is free to do what it chooses in these bands, and fortunately for us, we have proven to be good sharing partners.

This leads us to the case at hand, and the subject of this article: Here's a textbook case of the government exercising its rights, and the amateur community, represented by the ARRL, making sure it's the best fit we can get. If you're a 449-MHz repeater owner or user, you've got a vested interest in this. If you're not, you'll still want to understand how the system works for the next time. . . and you can bet there *will* be a next time!

As news of the Interdepartment Radio Advisory Committee's decision to place government wind profiler radar systems at 449 MHz spreads throughout the amateur community, several questions have been raised. (A government entity, IRAC assists the National Telecommunications and Information Administration in assigning frequencies to government radio stations and in developing and executing plans, procedures, and technical criteria.) To address these concerns, we are presenting the issues in the following question-and-answer format.

Q. What is a wind profiler radar system?

A. A wind profiler is a Doppler radar that measures atmospheric wind speed and direction directly above its location. Under a National Oceanic and Atmospheric Administration (NOAA) program, these systems will provide timely information on wind conditions from about 500 m (1500 ft) to 16.5 km (53,000 ft) above ground level. This information will allow aircraft to operate more safely while using less fuel. It will help meteorologists to predict more precisely and accurately the development and movement of weather phenomena such as severe thunderstorms. Profilers will also enable better prediction of the movement and dispersion of volcanic ash and atmospheric pollutants and mitigate the effects of environmental hazards.

Internationally, wind profilers in the future will be used to support commitments made by the US and other countries through the World Meteorological Organization to provide a worldwide network of stations making upper-air observations. These data are used in computer models of

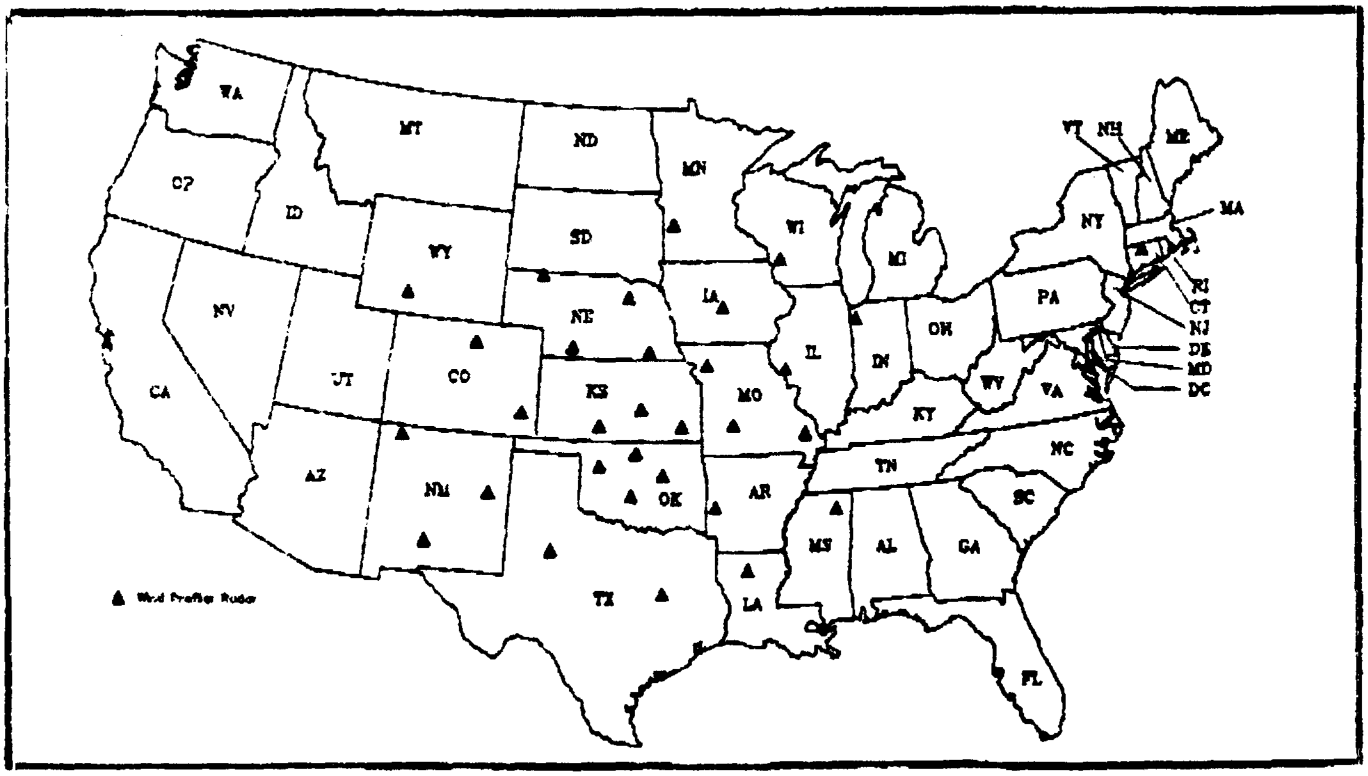


Fig 1—This map shows the locations of operating wind profilers. *(map by David Pingree)*

the atmosphere to make short, medium and long-range weather forecasts.

Q. ... do they operate?

A. Wind profiler systems have an antenna radiation pattern that is essentially straight up, with greatly reduced side lobes, to determine the velocity of the air within the main beam. The operating frequency determines the altitude of the observations, with frequencies near 400 MHz providing the altitude range needed by NOAA. Weather forecasting is increasingly dependent on computer models of the atmosphere. To produce accurate forecasts, these models require large quantities of timely wind observations, especially from altitudes of 6 to 15 km. Storm movement and development are strongly influenced by winds at these altitudes. These are also the altitudes used by commercial passenger aircraft whose schedules are partially dependent on the wind forecasts coming from these computer models.

NOAA's 404 MHz profilers operate in two modes, with 20 dB bandwidths of 400 kHz in higher-power mode and 600 kHz in the lower-power mode. The antenna lobe is aimed straight up (vertical) or skewed 15 degrees from vertical, during operation; energy in other directions, such as along the ground, is deliberately kept to a minimum.

Q. Do these profilers detect wind shear?

A. Wind profilers operating near 400 MHz will detect wind shear if it is occurring above 500 m (1500 ft). They will not detect very low level wind shear just above the ground, which may be hazardous to aircraft just touching down on an airport runway, but that can be done by wind profilers operating at a frequency around 1000 MHz.

Q. How many systems will be deployed? When? Where? On what frequencies?

A. Thirty-one systems, presently operating on 404 MHz, are located in the Midwest (from Nebraska to Texas, and Colorado to Arkansas, and one in Connecticut) generally away from metropolitan areas, major highways and airports. About another 200 profilers may ultimately be deployed on 449 MHz in the years to follow, depending on a number of factors, including the NOAA budget.

The locations of profiler sites for meteorological forecasting will probably be chosen to give a roughly uniform grid spacing, but the exact locations can vary by 20 or 30 miles. The detailed locations would be chosen to avoid, as far as possible, radio interference to and from other services.

It has been said that the 31 existing systems will have their operating frequencies changed to 449 MHz on September 30, 1993. An IRAC representative has, however, informed the ARRL that there is some flexibility of the September 30 date, indicating that some exceptions may be made, postponing the action temporarily or even indefinitely. All profilers may not have to move to 449 MHz.

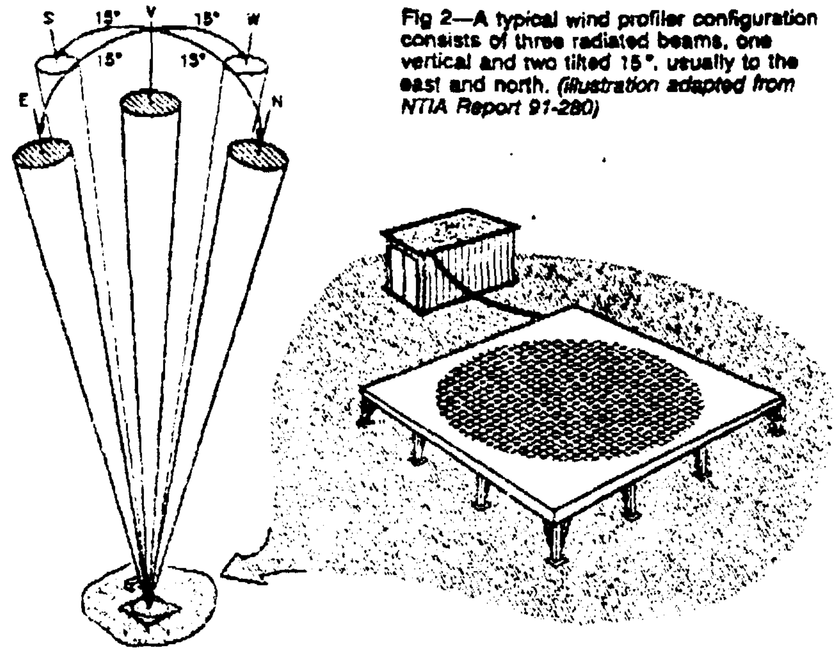


Fig 2—A typical wind profiler configuration consists of three radiated beams, one vertical and two tilted 15°, usually to the east and north. *(Illustration adapted from NTIA Report 91-280)*

Q. Are profiler systems frequency-agile?

A. Not really. If profiler radars could be tuned over a wide range of frequencies, this would further ease frequency management problems. These radars are, however, large complex units which involve major investment in the phased array antenna and receiver RF stages, and many parameters need to be optimized for each possible operating frequency. As a result, a given antenna design can be used only for frequencies varying over a range of plus or minus 1.0%.

Q. How many amateur repeaters will be affected by wind profilers?

A. Because of the generally remote location of the systems, and the fact that sharing problems will be minimized outside of a 30-mile radius of each system, the impact should be minimal. The vast majority of repeaters will be unaffected. The ARRL has the geographical coordinates for the existing 31 profilers and most amateur repeaters. We will compare the sets of coordinates to identify potential trouble spots.

There is another dimension to the situation: While most repeaters have outputs on 449 MHz, some have located their inputs there. Interference problems are possible, and technical solutions will need to be developed accordingly.

Q. 449 MHz is in an amateur band! They can't legally put them on our bands, can they?

A. Like most of the bands above 225 MHz, amateurs share the 420-450 MHz band on a secondary basis with the primary occupant, government radiolocation (radar). We must not cause interference to government operations, and we must tolerate any interference from them. The government is free to operate where it chooses in these bands, without consulting with the secondary users, although it has chosen to work with us to minimize potential interference problems.

Q. Okay, but why couldn't they stick them above or below our band and bother someone else? After all, we perform a public service with our repeaters.

A. The wind profiler is both a radiolocation device and a meteorological aid, and could reasonably be assigned a frequency in a band having either allocation. Unfortunately, there are no suitable met aids bands available in the technically acceptable frequency range. Continued operation at 404 MHz and operation anywhere in the 400-420 MHz range is prohibitive owing to the potential for interference to priority COSPAS/SARSAT systems (search-and-rescue satellites with wide passband transponders in low-earth orbit).

The NTIA/IRAC examined the alternatives. They looked at 225-400 MHz, which is *not* a radiolocation band. Government aeronautical radionavigation and fixed and mobile military services are accommodated there, precluding wind profiler operation.

They also looked at 450-470 MHz and determined that the effort required to displace stations in this congested land mobile, remote broadcast, public safety and industrial segment was prohibitive. The same situation was posed in the 470-512 MHz segment in many areas. So, the 420-450 MHz range, where government radiolocation is already the primary service (with amateurs secondary), looked to be the most viable.

Q. Were alternatives considered within the 420-450 MHz band?

A. Yes. The ARRL conveyed the fact that certain segments of this band require special protection: (1) 432 MHz, because it is the center for weak-signal experimentation. Operations here employ highly sensitive receivers and high-gain antennas; and (2) 435-438 MHz, an international satellite segment, where any vertically directed radar could cause interference to a satellite passing overhead.

Other roadblocks included the Amateur TV channels at 420-426, and 426-432 MHz. And when the Department of Defense lost its bid to keep the profilers out of 420-450 MHz altogether, it expressed its desire that, at the very least, the systems should be placed at a band edge to minimize the impact on existing, priority DOD operations on the band. IRAC then picked a 2-MHz-wide channel centered on 449 MHz.

Q. Where was ARRL during all of this? Isn't it supposed to fight for our frequencies?

A. First, no frequencies were lost—we still have full access to the band. Despite the fact that the ARRL had no opportunity to provide official input, IRAC was made well aware, informally, of the League's opposition to the Department of Commerce's proposals. IRAC knew we were there, and ARRL informed it of the concerns outlined above, and of the technical aspects of our repeaters.

Q. What is ARRL doing now to mitigate the effects of the government's decision?

A. The ARRL persuaded NTIA/IRAC and NOAA to take our needs into consideration when placing these systems. The League provided the government with technical characteristics of amateur systems, including frequency flexibility, repeater sensitivity, bandwidth, power and antenna gain. Although they didn't have to, IRAC, NTIA, and NOAA listened and agreed to take whatever practical steps possible to minimize the impact of wind profilers on existing users. Exactly how this agreement will be reflected in the Table of Frequency Allocations is still being worked out. Arrangements will be made with affected repeater groups.

Q. What is the nature of these arrangements and how will they be forged to accommodate affected repeaters?

A. As mentioned earlier, we are in the process of comparing profiler and repeater coordinates to identify specific problem areas. As soon as we know which repeaters will be affected, we will contact their trustees to provide advice and assistance. Initially, the ARRL will offer a technical evaluation of each case as necessary. Ultimately, affected repeater trustees will coordinate issues with NOAA. The goal is to localize the coordination as soon as possible.

Some technical solutions include moving the frequency of the repeater, or appropriate profiler siting. Shifting repeater or profiler antenna radiation patterns is another possibility: For example, a profiler null could be directed toward an affected repeater.

Q. Where was the FCC in all of this, and why weren't we notified of these proposals as required by the Administrative Procedures Act? Shouldn't we just complain to the FCC?

A. The FCC has no authority in US government frequency allocation matters. Simply, the FCC is responsible for nongovernment communications, and the NTIA is responsible for government operations, which have priority in this band. NTIA proposals and decisions are not subject to the same public participation requirements that apply to the FCC. The FCC is invited to observe IRAC meetings and may issue informal comments, but it has no authority in such matters. So, registering opposition with the FCC will have no effect as this is a government, NTIA/IRAC question.

Q. Why shouldn't we scream about this to Congress?

A. If a complaint was raised with Congress over this issue, we would put ourselves in the position of being judged by policy makers as to the merits of our position versus NOAA's position with respect to public interest and necessity. It would be an "Us versus Them" scenario with the other side able to claim the promotion of air safety and more accurate weather forecasting, where every US citizen would clearly benefit, as more compelling. Congress would also ask, "Can't you share?" If we answered "No," we could lose access to the 2-MHz segment entirely. If we answered "Yes," we would have gained nothing over the present sharing scenario. And, in the process of all of the above, we would lose a considerable amount of political capital that may be needed for future issues.

Q. Is there a bright side to this?

A. Yes, there is. Our secondary allocations are very vulnerable. The more successful sharing partners we have, the more allies we have in defending our continued access. Defense has been a powerful ally in the past, and no doubt will continue to be; but in the future we'll need all the help we can get.

Q. Okay, what should hams do if they believe they will be affected by the deployment?

A. Again, as mentioned above, the ARRL will attempt to notify repeater groups of potential problems. Amateurs should also notify their frequency coordinator and contact ARRL HQ for a technical evaluation of the specific case. Contact HQ's Regulatory Information Branch for further details.

Strays

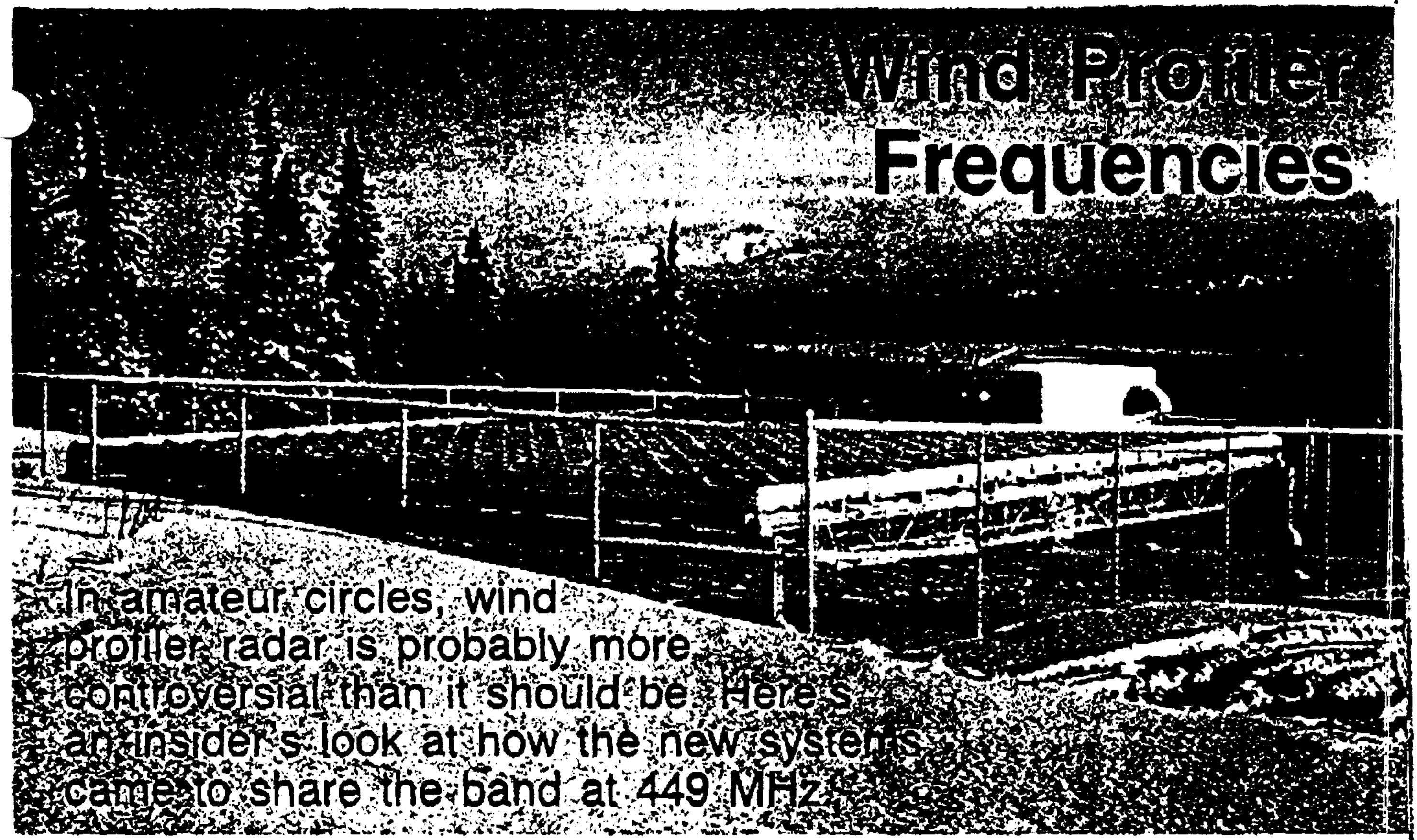
Hands-on experience; The Kimberling (MO) ARC felt that the 1991 Boy Scout Jamboree on the Air (JOTA) was an opportunity not only to put Scouts on the air, but to show them another side of Amateur Radio. Mark Duple, K0ONB, helps a couple of campers learn to solder electronic components as they work on their radio merit badges. The club participated in a JOTA outing at the Mill Creek Campground on Table Rock Lake in Missouri's Ozark Mountains. *(photo courtesy of Jim Davis, NQ0G)*

APPENDIX C

Wind Profiler Frequencies

By:

Richard Barth, W3HWN,
National Oceanic and Atmospheric Administration



Wind Profiler Frequencies

In amateur circles, wind profiler radar is probably more controversial than it should be. Here's an insider's look at how the new systems came to share the band at 449 MHz.

By Richard Barth, W3HWN
National Oceanic and Atmospheric Administration
Office of Radio Frequency Management
Room 3332
Federal Office Bldg #4
Washington, DC 20233

A typical wind profiler radar installation. Note the 40- × 40-foot antenna array and the perimeter fence, used for security purposes and to reduce side-lobe radiation.

Operational wind profiler radar systems are relatively new, although the National Oceanic and Atmospheric Administration (NOAA) has been experimenting with profiler technology for almost twenty years. Early experiments conducted at Commerce Department laboratories in Boulder, Colorado, showed the usefulness of profiler technology in measuring large-scale air movements—information of great value to meteorologists.

Profilers also provide significant (but non-obvious) benefits to aviation. They permit the tracking of ash clouds from erupting volcanoes, so aircraft can be routed safely around them. On several occasions, these clouds have nearly caused disasters by choking off the engines of jet aircraft. Profilers can also reduce aircraft operating expenses by letting planes ride favorable upper-air currents.

Government wind profilers have been authorized to use 449 MHz. What are wind profilers, anyway? Why did they end up on this frequency when it's already used by amateur repeaters in many parts of the country? And what impact, if any, will they have on ham radio?

In a sequence of two invited articles, NOAA engineers will answer these questions, giving an insider's perspective on how wind profilers work and how the decision was made to put them on 449.

One article, by Daniel C. Law, an engineer with NOAA's Forecast System Laboratory in Boulder, Colorado, will appear in an upcoming issue. It deals with the functions and characteristics of profilers—how they work and what they're used for.

This month's article was written by Richard Barth, W3HWN, who heads the Office of Radio Frequency Management for the US Department of Commerce.

Profiler Specifics

The performance of profiler radars is dependent on operating frequency, available bandwidth and the distribution of atmospheric turbulent eddies.

Like any radar, profilers depend on echo returns—signals reflected from the target the radar is seeking. Common radar targets are planes, boats and speeding cars, but for profilers, the target is refractive index fluctuations in the air. Profiler signals are reflected from turbulent eddies, places where the air swirls much like water going down the drain. A return is created when the physical size of an eddy approximates a half wavelength at the radar's operating frequency. Eddies are not uniformly distributed throughout the atmosphere: Large eddies exist from ground level to significant altitudes, while smaller ones drop off rapidly as altitude increases.

The result is that lower-frequency profilers work well at all altitudes, while higher-frequency profilers are useful primarily close to the ground. Further, use of the wider bandwidths available at higher frequencies makes it possible to get finer detail close to the ground, where it is most useful.

Finding Frequencies

The useful frequency range for profilers is roughly 50-1200 MHz. For its planned systems, NOAA determined that frequencies between 200 and 500 MHz provide the best performance.

Government radars operate in frequency

bands allocated to them by the National Telecommunications and Information Administration. (The NTIA exercises the President's power under the Communications Act to regulate radio use by agencies of the Federal government.) It is in these bands that they must stay if they expect to receive the protection "the system" affords to those who play by the rules.

When different services share a frequency band, two types of allocations—primary and secondary—set them apart. Primary users can claim protection from secondary users. Other things being equal, systems with equal status share on a "first come, first served" basis. Systems operating without an allocation must do so on a non-interference basis, termed "NIB." They are not permitted to interfere with, and must accept any interference they receive from, stations operating with an official allocation. Profilers will be an important national asset, so they need a frequency on which their operation can be protected. In other words, a primary allocation is needed.

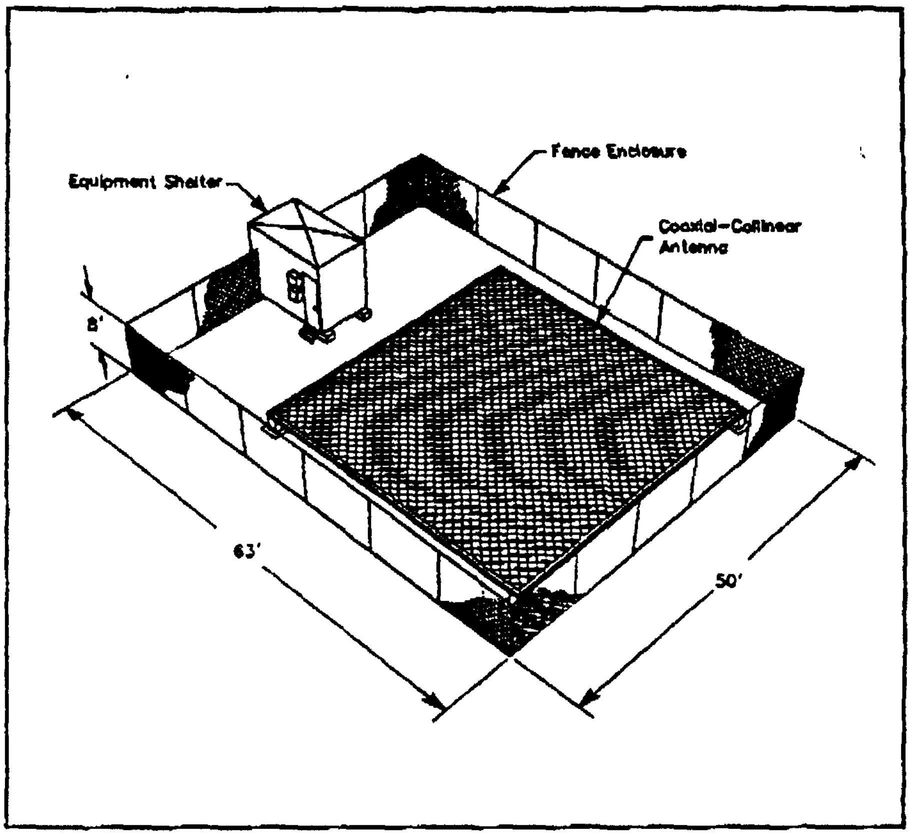


Fig 2—A graphic depiction of the wind profiler site shown on page 22.

Not long ago, there were two radar bands in the range of interest. The first was 216-225 MHz. Hams are familiar with the changes recently made there. What's left is a secondary allocation, to military radars only, from 216-220 MHz. There are also secondary allocations to the fixed service, land mobile and aeronautical mobile. Maritime mobile has a primary allocation and is widely used on rivers and lakes throughout the US. The ARRL has petitioned the FCC to permit amateur operations below 220 MHz. Worse yet, there is an international footnote to the allocation tables stating that radars in this band should be phased out. All in all, the band presents a pretty inhospitable climate for NOAA's planned national profiler network.

The only other radar band in the region of interest is at 420-450 MHz, where government radars have the only primary allocation. For years, these radars have successfully shared their territory with radio amateurs, who have a secondary allocation. NOAA couldn't use this band, however, because radar operations were limited to the military by footnote G2 to the US Tables of Frequency Allocations. As a result, NOAA built a profiler test bed, called the Demonstration Network, using 404.37 MHz as its operating frequency. A number of other experimental profilers were also built in the 403-406 MHz band, which is officially allocated to radiosondes, or "weather balloons."

There are uplinks to meteorological satellites below 403 MHz, so this part of the band had to be avoided. The 403-406 MHz band is not allocated to radars, so profilers here operate NIB, which is acceptable because they're still experimental and not part of an operational system.

Soon after the first profilers began operating in this band, they began to interfere with NOAA's SARSAT (Search and Rescue Satellite Aided Tracking) network. SARSAT receives emergency signals from EPIRBs (Emergency Position Indicating Radio Beacons) on 406.05 MHz. COSPAS satellites, the Russian equivalent to SARSAT, had the same problem. Although profiler signals are "clean," SARSAT receivers are so extraordinarily sensitive that they were being desensitized by the profilers.

As a short-term solution, profilers are turned off whenever a SARSAT or COSPAS satellite passes through the main beam. This has permitted the small Demonstration Network to continue its assessments. The larger operational network would produce so much noise from its many overlapping side lobes that SARSAT's lifesaving mission would be badly compromised. This is unacceptable; it became clear that another band had to be found for profilers.

The radar band at 420-450 MHz was the only reasonable choice. After extended study, the NTIA decided that profilers

WARC-92 Declines to Designate Interim Frequency for Wind Profilers

While the question of frequency allocations for wind profiler radars was not on the agenda for WARC-92, the conference adopted a recommendation that invites the CCIR to continue its studies relating to wind profiler radars and invites the ITU Administrative Council to consider placing the question of appropriate frequency allocations for their operational use, in the general vicinity of 50, 400, and 1,000 MHz, on the agenda of the next WARC.

The US had sought a provision in the recommendation designating 449 MHz as an interim frequency for wind profiler radars internationally. The IARU position on the matter was that designation of an interim frequency is premature until the above-mentioned CCIR studies are completed. (These studies relate to the technically suitable frequency bands, associated standards and frequency sharing criteria necessary for compatibility with services that may be affected.)

The Conference took the same position as the IARU. The recommendation adopted at WARC-92 urges administrations to avoid using 402-406 MHz, in order to avoid interfering with the COSPAS-SARSAT system, but is silent with regard to an interim frequency.

That the US did not achieve the designation of an interim frequency for wind profiler radars at WARC-92 has no effect on the use of the frequency within the US. The band 420-450 MHz is allocated for primary use by the Radiolocation Service in the US. (In most of the world, radiolocation is secondary at 440-450 MHz.)—*David Sumner, K1ZZ*

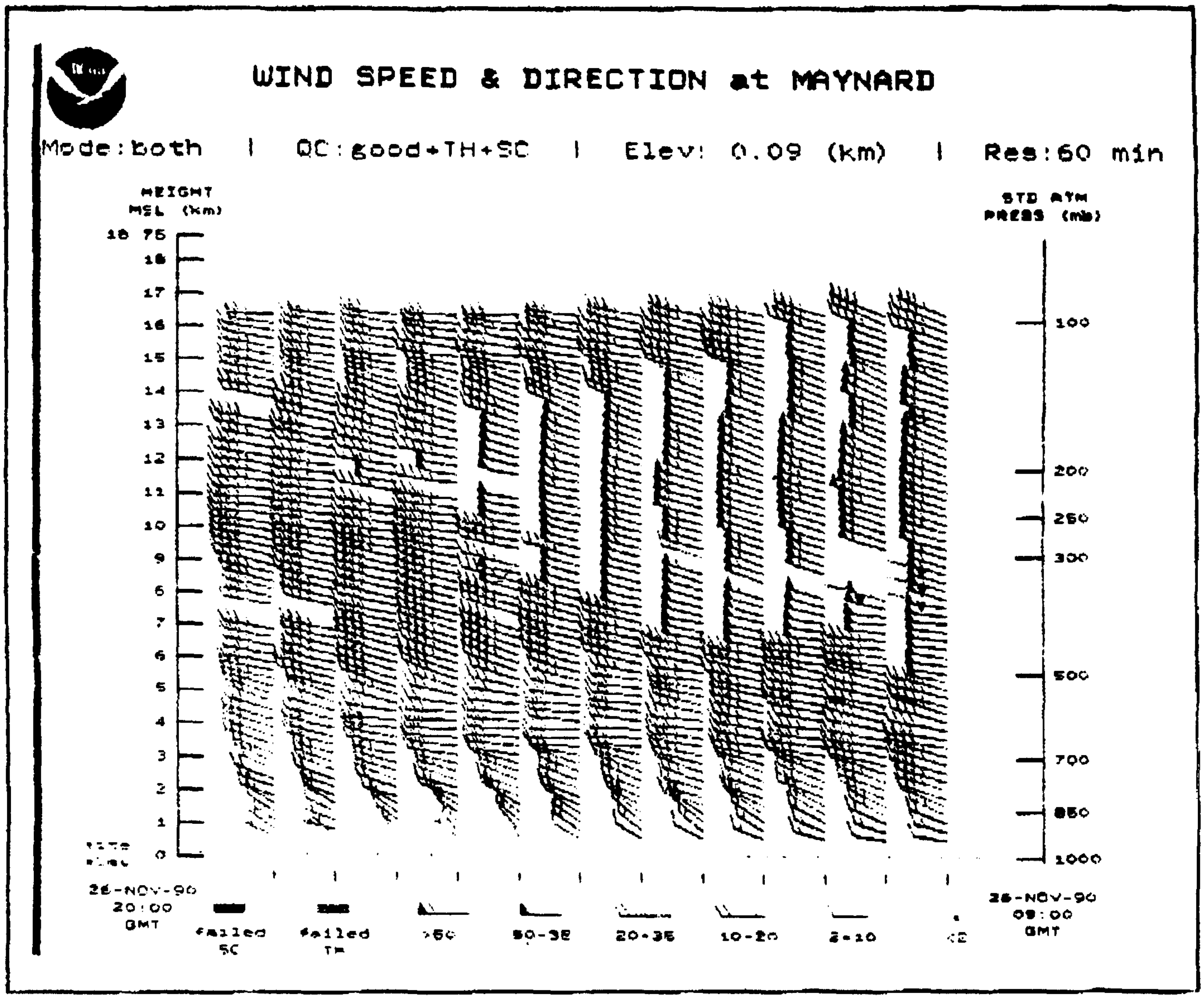


Fig 3—This output from a wind profiler radar shows wind speed and direction from 0 to 19 km above the site over a 12-hour period.

could use the band, but would have to operate as close as possible to the upper edge. This would minimize interference to the military, which uses the band for airborne and other radar operations involving national security. Profilers are permitted a bandwidth of no more than two megahertz, so "as close as possible" means 449 MHz.

Sharing the Band With Hams

The 448-450 MHz area is used by amateur voice repeaters in many parts of the country. This fact was considered by the NTIA, which decided that sharing between profilers and amateurs is feasible. There are several reasons for this. Profilers radiate straight up (or almost so): The main beam is never more than about 15° degrees from the zenith. The presence of side lobes at low elevation angles is minimized by the design of the antenna, which is a square forty feet on a side, and by the presence of a metal screening fence around the profiler site.

Radar returns from the ground, called "clutter," are much stronger than those from the clear atmosphere. Profilers would not work if side lobes, hence clutter, were not kept to a very low level. Also, repeaters in the 440-MHz band tend to cluster near population centers. Profilers, on the other hand, will be built in rural areas where electrical noise is reduced and land is cheaper.

Should it prove necessary to install a profiler near an existing repeater site, a number of steps can be taken to minimize problems. In the eastern half of the US and in northern California, 449 MHz is used almost exclusively for repeater inputs. This means that eliminating profiler interference to a single ham site—the repeater—will solve the problem in these areas.

Profiler antennas have definite nulls in their side lobe radiation patterns, one of which can be aimed at the repeater. Repeaters also have nulls, or can be made to have them. These, too, can be used to advantage. In areas where 449 MHz is used for repeater outputs, interference will be minimized by the fact that mobile stations typically have low-gain antennas—a couple of decibels for a car installation, still less for a rubber duck antenna. A test by the ARRL showed a profiler signal to be inaudible five miles away, in a typical FM receiver connected to a mobile whip antenna.

Technical concerns, while real, appear to be manageable. The National Weather Service, the part of NOAA that will operate the profiler network once it's in place, has a long record of cooperation with the amateur community in SKYWARN and other public service activities. We expect that this sort of cooperation will continue, and intend to do our best to ensure that it does. Installation of NOAA's network is not expected to begin for another five to ten years. During that time there will be plenty of opportunity to plan profiler installations in a way that will impose the fewest possible constraints on amateur operations.

APPENDIX D

Upper Air Meterological Measurements for the Lake Michigan Ozone Study

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INTRODUCTION

In recent years, the Lake Michigan Air Quality Region (LMAQR), which encompasses parts of Wisconsin, Illinois, Indiana, and Michigan, has experienced numerous violations of the 12 pphm ozone National Ambient Air Quality Standard. Portions of all four states in the region have been designated nonattainment areas for ozone. Control strategies adopted to date have not achieved the desired reductions in ozone levels in the region. Despite a reported decrease in ozone precursor emissions during the 1980s, there has not been a corresponding decrease in the number of ozone exceedance days or in maximum ozone concentrations. These exceedances may be caused by a combination of local emissions, direct transport of ozone and precursors from upwind areas, and carryover of previous day's emissions. Both direct transport and carryover mechanisms may involve processes that occur over Lake Michigan. Evidence suggests that the complex meteorology of the lake-shore environment may be the most important factor in determining concentrations patterns, although uncertainties in emissions and chemical mechanisms must also be better understood before adequate control strategies can be implemented.

To develop a better understanding of ozone source-receptor relationships in the LMAQR, the four states that comprise the region and the U.S. Environmental Protection Agency (EPA) are sponsoring the Lake Michigan Ozone Study (LMOS). The background and purpose of the study are described in a scoping study report and in a conceptual design plan[1,2]. The major elements of the LMOS include:

> A field measurement program to monitor air quality and meteorological variables on a routine basis and to collect an enhanced data base of surface and aloft air quality and meteorological observations during periods of high ozone concentrations;

> Analyses of historical data and data collected during the field study;

> Preparation of an updated emissions database; and

> Development and evaluation of numerical models to simulate the meteorological and air quality mechanisms that occur during ozone episodes.

The field measurement program was conducted during the summer of 1991. The overall goal of the field study was to provide data of known quality to support the development and evaluation of the meteorological and air quality models. Specific technical objectives of the field study included:

> Characterizing the prevailing meteorology of the study area, including transport patterns and atmospheric structure;

> Characterizing the air quality conditions and pollutant fluxes in the study area; and

> Developing an understanding of the important source-receptor relationships, including the key dynamic processes.

The purpose of this paper is to describe one of the components of the LMOS field study, namely the operation of a network of fourteen (14) sites where upper air meteorological data were collected. Other measurement components of the LMOS field study included an expanded network of surface air quality and meteorological sampling stations; operation of a suite of instrumented aircraft to measure aloft air quality; and special studies such as using sulfur hexafluoride (SF_6) as a tracer to try to monitor air flow patterns along the western shore of Lake Michigan.

Of the 14 LMOS upper air sites, seven were equipped with rawinsonde sounding systems that measured vertical profiles of winds, temperature, and moisture during Intensive Operational Periods (IOPs), which were called when weather and pollutant forecasts indicated that high ozone levels were expected in the region. Three of the balloon sounding sites were located on small boats that deployed onto Lake Michigan during IOPs. One of these boat-based stations also measured vertical profiles of ozone concentrations using a commercial ozonesonde. The rawinsonde stations were operated by Sonoma Technology Inc. (STI) and Technical and Business Systems, Inc (T&B).

The remaining seven upper air sites were equipped with 915 MHz Doppler radar wind profilers that measured winds aloft continuously during the study. Two of the profiler sites were also equipped with Radio Acoustic Sounding Systems (RASS), which measured virtual temperature as a function of altitude. The radar profilers were operated by STI and Radian Corporation.

In the following sections, we present an overview of the upper air measurement program, including descriptions of the sampling equipment, the network design and sampling strategy, operations summaries, and the data processing and quality control (QC) procedures that were applied to the data. We also present some examples of preliminary analyses of the upper air data.

OVERVIEW OF THE UPPER AIR PROGRAM

The goal of the upper air measurement component of the LMOS was to provide data to support objective analyses and numerical modeling of the meteorological processes affecting the formation and transport of ozone in the LMAQR, especially during periods of high ozone concentrations. The upper air network was designed to monitor regional-scale meteorological processes and the evolution of mesoscale circulations such as lake breezes. Some of the specific technical objectives of the upper air measurement program included:

> Provide meteorological fields to initialize, bound, and otherwise optimize the output of prognostic meteorological models used to predict winds, temperature, humidity, and mixing depth throughout the study domain;

> Provide a field of observations to evaluate the performance of the meteorological models; and

> Provide a field of observations to study meteorological phenomena within the study domain.

Description of Measurement Systems

Table 1 identifies the locations of the 14 upper air sites and lists the equipment used at each site. Seven of the sites were equipped with LAP-3000 radar wind profilers. The sites at Zion Shoreline (ZIS) and Grafton (GRF) were also equipped with RASS instruments for measuring virtual temperature as a function of altitude. These instruments were developed by researchers from the Aeronomy and Wave Propagation Laboratories of the National Oceanic and Atmospheric Administration's (NOAA) Environmental Research Laboratory (ERL)[3,4]. Radian and STI have entered into a Cooperative Research and Development Agreement (CRDA) with NOAA/ERL to commercialize this technology. Many of the applications to date for the 915 MHz radar wind and temperature profiler have been in regional air quality studies with objectives similar to those of the LMOS[5,6]. However, this was the first use of a commercial version of the instruments. Table 2 summarizes the operating characteristics of the profilers deployed for the LMOS.

The LAP-3000 is a small, portable, PC-based Doppler radar profiler for measuring vertical profiles of winds in the lower troposphere. The profiler transmits radar energy at 915 MHz along three beams (one pointed vertically and two orthogonal beams tilted 15° from the vertical). Some of this transmitted energy is scattered by inhomogeneities in the index of refraction in the clear atmosphere and received back at the radar. Vertical and horizontal velocity components are then determined by measuring the Doppler shift of these received signals. With appropriate algorithms, horizontal wind speeds and directions are computed as a function of altitude and corrected for vertical air motions by the LAP-3000's data acquisition system.

The principle of operation behind the RASS instruments is that by transmitting acoustic energy into the vertical beam of the radar at wavelengths matching the half-wavelength of the radar, Bragg scattering will occur which will allow the speed of the acoustic signals to be tracked by the radar. Knowing the speed of sound as a function of altitude, virtual temperature (T_v) profiles can be calculated after correcting for vertical air motions.

The seven rawinsonde stations were all equipped with VIZ W-9000 Loran-based navaid sounding systems. The three boats used to collect upper air data over Lake Michigan were operated by North American Weather Consultants (NAWC) and were based at a marina located in Waukegan, IL. NAWC collected surface air quality and meteorological data on the boats and their crew helped STI's operator perform the upper air soundings. The boats departed to their pre-assigned stations on Lake Michigan at the beginning of IOPs and remained on station (as conditions permitted) until the experiment was terminated by the LMOS Field Manager.

At each rawinsonde station, a radiosonde (model VIZ Mark-II) attached to a helium-filled weather balloon was used to measure atmospheric pressure, temperature, and relative humidity as the balloon ascended. The balloon was inflated with enough helium to produce an ascent rate of approximately 3 m/s. The radiosonde's data were transmitted to a ground-based receiver and data acquisition system, where they were converted to engineering units based on calibrations established by the manufacturer. The altitude of the balloon was computed by integrating the hydrostatic equation using the pressure, temperature, and moisture data. Winds aloft were obtained by measuring the change in the balloon's position as a function of time and altitude. The VIZ W-9000 determined the position of the balloon using the Loran-C radio navigation system. Table 3 lists the specifications of the VIZ W-9000 sounding systems used in the field study. Given the 1.2 second sampling rate for the radiosonde's sensors reported in Table 3 and assuming a 3 m/s ascent rate, the vertical resolution of the radiosonde's data was approximately 3 to 5 m. Likewise, the 15 second averaging interval for the wind calculations reported in Table 3 corresponded to a vertical resolution of approximately 45 m for the wind data.

At the Mid-Lake Boat (BML) station, ozone soundings were performed in addition to the rawinsoundings. The ozone data were collected using an electrochemical concentration cell (ECC) ozonesonde manufactured by Science Pump, Inc. The ECC ozonesonde measured ozone concentrations by generating an electrical current in proportion to the rate at which ozone was pumped through the cell. The electrical current was generated by potassium iodide solutions of different concentrations contained in separate cathode and anode chambers. Komhyr and Harris[7] describe the ECC ozonesonde and its principles of operation. The ozonesonde was attached to a modified VIZ Mark-II radiosonde for the ozone soundings so that wind, temperature, and ozone data were collected simultaneously. The specifications of the ECC ozonesonde are included in Table 3.

Each rawinsonde station was equipped with a digital aneroid barometer (Peet Bros. Ultimeter) to measure station pressure prior to the launch of the balloon. The measured station pressure was used to correct any offsets in the surface pressure reported by the radiosonde. The site barometers were calibrated at the beginning and end of each IOP against a reference digital aneroid barometer. The barometer used for these calibrations was an Atmospheric Instrumentation Research, Inc. (A.I.R.) model AIR-HB-1A.

Network Design and Sampling Strategy

The distribution of the sites in the upper air network is shown in Figure 1. The basis for the general design of the network was to use the radar profilers to collect continuous observations along the shoreline of Lake Michigan in an attempt to monitor the onset and structure of the lake breeze; the rawinsonde stations were deployed so as to monitor conditions along the boundaries of the study area and over Lake Michigan itself.

Data collection was most intense along the so-called two-dimensional data plane (2DDP) shown in Figure 1. The two radar profiler sites located near Benton Harbor, MI (BHE and BHA) formed the eastern end of the 2DDP. The Mid-Lake Boat (BML) station was deployed during IOPs to collect rawinsoundings and ozone soundings in the middle of the 2DDP. Likewise, the South Lake Boat (BSL) site collected rawinsoundings during IOPs approximately 5 km offshore of Zion, IL. Three upper air sites were positioned close together between Zion Shoreline (ZIS) and Zion 5-Mile (Z5M) to examine the spatial and temporal characteristics of lake breeze circulations. Both ZIS and Z5M were equipped with LAP-3000 radar profilers. The Zion 2-Mile site (ZIO) was equipped with the VIZ W-9000 rawinsonde system. Data were collected at this site only during IOPs. A second data plane (not shown in Figure 1) was formed by the Grafton and Slinger (SLI) radar profiler sites and the North Lake Boat (BNL) rawinsonde station.

Each day of the field study, the LMOS Field Manager decided if weather and pollutant conditions were favorable for beginning an IOP. The Field Manager would issue a "go" to begin sampling the day before an IOP was to begin. Once an IOP was started, the rawinsonde stations began performing soundings at 0600 CDT on the first day of the IOP and continued performing soundings every three hours until the experiment was terminated by the LMOS Field Manager. To meet this schedule, the three boats had to leave the Waukegan marina shortly after midnight on the day the IOP was to begin to reach their designated station in time to launch the 0600 CDT sounding. The final sounding of an IOP was scheduled to be taken at 2100 CDT on the last day of an experiment. The ozone soundings were taken on the Mid-Lake Boat four times daily on IOP days. Ozone soundings were collected at 0300 CDT, 1200 CDT, 1500 CDT, and 1800 CDT. The 0300 CDT ozone sounding was not taken on the first day of an IOP since the BML boat was still travelling to its designated station.

All soundings were scheduled to be performed to 500 mb (approximately 5500 m msl) as conditions permitted. While a sounding was underway, the station operator monitored the incoming data and routinely checked the general performance of the data acquisition system. If the operator detected any problems that caused significant data losses or produced erroneous data before the balloon reached an altitude of at least 1500 m agl, the operator attempted to perform a new sounding (as conditions permitted).

The radar profilers operated continuously during the field study and the sampling strategy was the same regardless of whether or not an IOP was underway. The data acquisition system of each profiler was programmed to compute hourly-averaged wind profiles for each of two modes of operation. In the first mode, each pulse of energy transmitted by the profiler was 100 m in length, that is, the depth of column of air being sampled was 100 m. With this first mode, the vertical resolution of the wind data was the same as the pulse length, namely 100 m. In the second mode, the pulse length, and thus the sampling volume and vertical resolution, was increased to 400 m. The longer pulse length meant that more energy was being transmitted for each sample, which improved the signal-to-noise ratio (SNR) and thus increased the maximum altitude to which data could be collected. These two modes were chosen as the best compromise between achieving the best vertical resolution possible and maximum altitude coverage.

With the 100 m mode, the maximum altitude to which data were collected varied from to 1 to 3 km altitude, depending on atmospheric conditions. With the longer 400 m pulse length, the maximum altitude to which data were collected varied from 3 to 5 km agl altitude, again depending on atmospheric conditions. To offset some of the loss of vertical resolution associated with the 400 m mode, a technique called "over-sampling" was used. A 400 m pulse length was still transmitted, but overlapping volumes were sampled so that wind observations were collected every 200 m (the column of air over which the winds were averaged was still 400 m deep, however).

When profiling for winds at SLI, Z5M, BHE, and BHA, each of the three beams of the radar was sampled for approximately 20 seconds in each mode. Thus, it took about 1 minute to measure the horizontal and vertical components of the wind in each mode. This meant that each mode's hourly-averaged wind profile was based on 30 1-minute samples. When profiling for winds and temperatures at ZIS and GRF, the first 10 minutes of each hour were used to collect RASS data, from which an averaged profile of virtual temperature was computed. Because the SNRs associated with RASS sampling tended to be very large, a shorter pulse length was used (60 m) to better resolve the vertical temperature structure. The remaining 50 minutes of each hour were used for routine wind profiling. Thus, the averaged wind profiles in both the 100 m and 400 m modes collected at ZIS and GRF were each based on 25 1-minute samples. All of the 1-minute data were archived during the field study; these data will be used to examine finer-scale features of lake breezes than the 1-hour averaged data will permit.

SUMMARY OF FIELD OPERATIONS

During the planning and design phase of the field study, general areas were selected where the rawinsonde and radar profiler measurements were desired. During the spring of 1991, STI, T&B, and Radian staff located specific sites suitable for rawinsonde and radar profiler operations and made arrangements for site leases, shelter, power, telephone service, and security. The team of upper air operators who would perform the balloon soundings was also selected during the spring. Most of the upper air operators were undergraduate or graduate majors in meteorology from the University of Wisconsin (UW) at Madison. Two operators were assigned to each of the shore-based upper air sites. One STI operator was assigned to each of the three boats. He was assisted by the NAWC crew who operated the boat. In addition, a UW student was hired as a field technician to help with the collection and processing of the radar profiler data.

Summary of Rawinsonde Field Operations

The STI and T&B field management team arrived in the field in early June to prepare the upper air sites and to set up a field operations center, which was located at the Waukegan Airport in Waukegan, IL. Prior to the start of field operations, a 3-day training sessions was held at the operations center for all the upper air operators as well as the NAWC crew chiefs and crew members assigned to the boats.

During the training session, the operators were taught how to perform soundings with the VIZ W-9000 sounding system. The operators performed soundings jointly with their partners and individually until the field management staff were satisfied that each operator could successfully operate the sounding equipment. Each member of the upper air team was instructed in the standard operating procedures (SOP) for collecting the upper air data and for completing all required documentation. The training session also covered the procedures for transferring the data from the field to the operations center and for maintaining routine and emergency communications with the field management team. Additional on-site training was provided individually to each operator during installation of the sounding equipment at each site. The operators assigned to the Mid-Lake Boat were given special training in the procedures for performing the ozone soundings.

Field operations formally commenced on June 12, 1991 when a "test day" was conducted for all the LMOS participants. Upper air soundings were performed at 1200 CDT and 1500 CDT by all stations, with the operators required to follow all sounding procedures just as though an actual IOP was underway. The intensive operational period began on June 17, 1991 and continued until August 9, 1991. During this time, the upper air field manager or his designee spoke daily with the LMOS Field Manager regarding the readiness and status of the upper air network for sampling for the next 24 hours.

Two IOPs were conducted during the field study. The first intensive occurred during the four day period June 25-28, 1991. The second IOP took place during the three day period July 16-18, 1991. A total of 364 rawinsoundings (52 per station) were scheduled during these two experiments. Likewise, a total of 26 ozone soundings were scheduled to be collected by the Mid-Lake Boat station. In addition, a limited set of upper air data were collected on July 31, 1991 as part of an aircraft intercomparison study. During this intercomparison, two rawinsoundings were taken by the South Lake Boat (BSL) at a position approximately 15 miles east of ZIS. One rawinsounding was performed at the Zion 2-Mile site during the intercomparison.

Both stations also measured vertical profiles of ozone using the ECC ozonesondes during the three soundings.

In general, operations of the rawinsonde network proceeded smoothly during the field study with only a few problems that adversely affected data recovery and quality. Table 4 summarizes data recovery during the two IOPs at the seven balloon sounding stations. The four land-based sites performed all of their scheduled soundings for a data recovery rate of 100%. Data recovery on the three boat-based stations was somewhat lower owing to adverse operating conditions, which are discussed below. The boats collected 125 of their scheduled 156 soundings, or 80% of the scheduled soundings. Overall, the upper air rawinsonde network collected 92% of the scheduled rawinsoundings and 77% of the scheduled ozone soundings.

Equipment problems at Kankakee (KAN) during the first IOP caused some loss of data above 800 m agl; a faulty 404 MHz receiver, which caused weak reception of the signals from the Mark-II radiosondes, was the source of the problem. A spare VIZ W-9000 was installed at KAN before the June 15, 1991 1500 CDT sounding. It functioned properly until the June 26 0000 CDT sounding, when its Loran receiver began to fail. Most of the wind data were lost in the June 26 soundings through the 1800 CDT sounding while the field team worked with the manufacturer to try to isolate and correct the problem. Beginning with the 2100 PDT sounding on June 26, wind data at KAN were obtained by tracking the balloon visually using an optical theodolite. VIZ shipped a replacement Loran receiver to the field, which was installed at Kankakee in time for the 1500 CDT sounding on June 27, 1991. The new unit worked properly for the remainder of the IOP.

During the first IOP, the Mid-Lake Boat suffered a power outage and fire that prevented the upper air operators from performing several scheduled soundings (including several ozone soundings) and also damaged the sounding equipment. With the concurrence of the LMOS Field Manager, the VIZ W-9000 assigned to the North Lake Boat was transferred to the BML boat early on June 27, but it too experienced signal losses due to continued electrical problems on the BML boat. These problems caused intermittent data losses in many of the BML soundings during the first IOP, particularly at levels above approximately 850 mb (roughly 1500 m msl). However, these problems were corrected by the second IOP (with the help of a portable auxiliary generator) and all scheduled BML soundings were performed for the July 16-18, 1991 episode. Rough weather during both IOPs forced the North Lake Boat to return to port for several hours during each IOP, so some BNL soundings were not performed.

Summary of Radar Profiler Field Operations

STI and Radian staff arrived in the field in late May to deploy and test the radar profiler equipment. Once each site was established, a field engineer monitored the operation of the instrument for 1 to 2 days and adjusted its operating characteristics as appropriate to reduce the effects of ground clutter and to maximize data recovery. Prior to the start of the intensive operational period, a senior engineer from NOAA/ERL/WPL traveled to the field to check each profiler and to "fine-tune" each instrument to its particular operating environment.

At each profiler site, the wind and temperature data were stored on the hard disk of the LAP-3000's personal computer. The data were also sent via serial port to a second personal computer located at each site. This so-called "front-end" computer was used to store copies of the data and to provide remote communications to a network hub computer located at the field operations center at the Waukegan Airport (the front-end computer was also used to send data to STI's offices in Santa Rosa, CA). The network hub automatically called each LAP-3000 front-end computer once per day and down-loaded the previous 24 hours of data. Manual operation of the communications system was also used so that the most recent data from a profiler site could be obtained at any time if needed (e.g., to support real-time operations during the tracer experiments).

In addition to the remote transfer of data from the profiler sites to the operations center, a field technician visited each site weekly during non-IOP periods and immediately before and after each IOP to check on the condition of the equipment and to make back-ups of the data collected since the last visit.

One component of the LMOS field study involved independent quality assurance audits of each profiler site. These audits, performed by AeroVironment Inc. (AV), included a review of system operating procedures by the auditors and an intercomparison of wind data collected by the profiler with wind data collected by an AV Doppler acoustic sounder (sodar) that was brought to each profiler site and operated for approximately 24 hours. The intercomparisons were based on averaging winds measured by the sodar and profiler over comparable volumes of the atmosphere and computing average and maximum differences between the two data sets as a function of altitude.

Table 5 summarizes AV's results from these intercomparisons. We have also calculated rms differences between the profiler and sodar data and included those results in Table 5. Although there are differences between the two measurement techniques and in the sampling and data reduction procedures used by each instrument, the results shown in Table 5 indicate that there was quite good agreement between the two instruments. Dye and Lindsey[8] discuss the performance of the profilers and the results of the audits in greater detail.

There was one significant issue that adversely affected data recovery by the profilers. Several key components of the profilers were also used in weapons systems deployed for the war in the Persian Gulf. As a result, these components were not available from their suppliers in time to meet the schedule of the LMOS field study. Instead, substitute parts, designed by the engineers at NOAA's Aeronomy Laboratory and built by Radian, were used in each of the profilers. While these parts performed satisfactorily in nearly all respects, they did limit the minimum altitude at which winds could be routinely measured to approximately 150 to 200 m agl. The maximum altitudes that could be sampled successfully were also somewhat lower than would otherwise have been expected. Likewise, the RASS at Zion Shoreline did not perform well at the beginning of the field study, in part due to these equipment problems. By the end of July, Radian had received a sufficient number of parts to upgrade the Zion Shoreline profiler to the specifications originally called for in the NOAA design. Data recovery did improve at ZIS after this upgrade.

While waiting to upgrade the Zion Shoreline profiler, the acoustic sources from the Grafton RASS were moved to ZIS in an attempt to improve recovery of temperature data at ZIS. Data recovery did improve at Zion Shoreline with the addition of the extra acoustic sources, and more improvement in RASS performance came when the custom-made components of the ZIS profiler were replaced with their commercial versions. The Grafton RASS was moved on 7/2/91 and replaced on 7/29/91. No temperature profiles were measured at Grafton during this period.

A few other minor problems affected data recovery by the profilers. A storm system passed through the region on 7/7/91 and slightly damaged the profilers at Grafton and Benton Harbor East, causing a few days loss of data while they were being repaired. Occasional power outages caused data losses at Benton Harbor Airport and Gary. None of these problems affected data recovery during the IOPs, except for a loss of 22 hours of data at BHA when power was off.

DATA PROCESSING AND QUALITY CONTROL

The goal of the data processing and quality control element of the upper air program was to produce a data base of rawinsonde and radar profiler observations at Level 1 validation. For the LMOS, Level 1 validation meant that each rawinsounding and each 24 hours of LAP-3000 wind and temperature profiles had been subjected to quantitative and qualitative reviews for accuracy, completeness, and internal consistency and that the validity of each data point was identified by the use of quality control flags. Furthermore, Level 1 validation meant that erroneous data had been removed from the data base and that questionable data were identified to users via the QC flags. Quantitative screening was generally performed